Assessment of Eutrophication in Estuaries and Coastal Waters

Neuse River Estuary, North Carolina, USA

Ria Formosa coastal lagoon, Portugal

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NJ Water Monitoring Coordinating Council
Delaware River Basin Commission, W. Trenton, New Jersey
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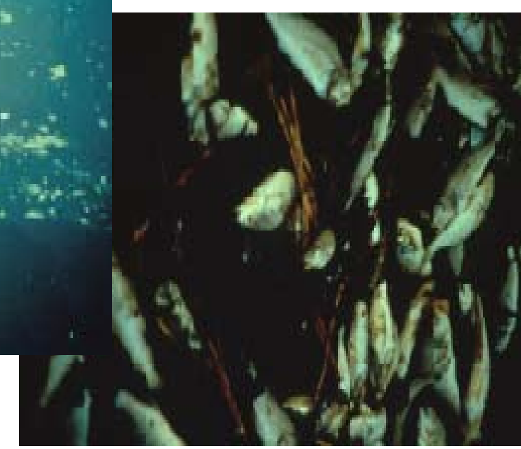
The Problem – The Model

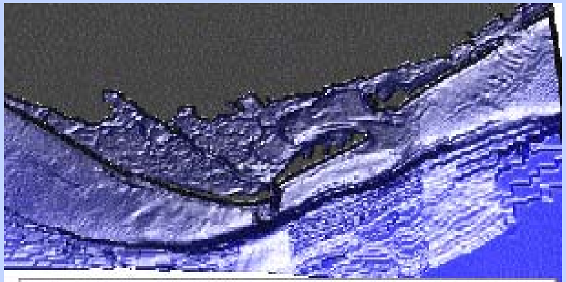
Symptoms and Consequences of Nutrient Enrichment

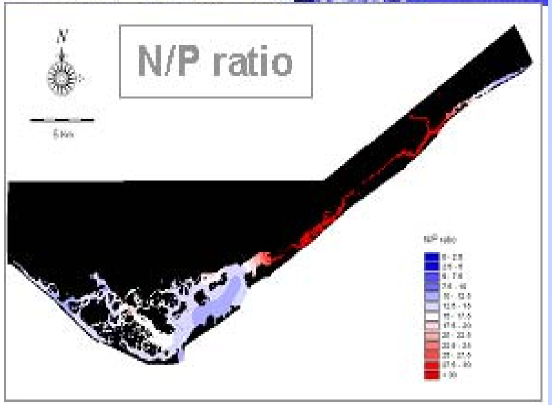
Nutrient Inputs and Processing	Primary Impacts	Secondary Impacts	Consequences of Symptoms
Increased N and P concentration	High algal production Loss of water clarity Epiphyte problems Macroalgal problems	Loss of SAV Low D.O Nuisance/Toxic Blooms	Fish kills Loss of habitat Human health risks Loss of Tourism Closed fishing grounds

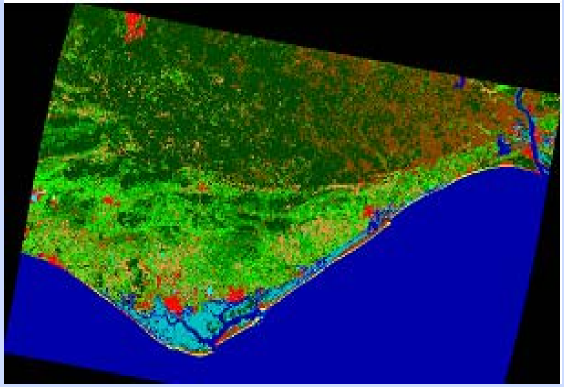


The Context

- US Clean Water Act of 1972, and US Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, EU Water Framework Directive (2000/60/EC), EU UWWTD and Nitrates Directives – Definition of Sensitive Areas and Vulnerable Zones
- Eutrophication is a process rather than a state
- Elevated nutrient concentrations may or may not be associated to human loading
- Eutrophication may or may not be associated to high nutrient loads or concentrations (e.g. Cloern, Howarth et al, Tett et al)
- Eutrophication is a significant problem worldwide (US, EU, Baltic, Mediterranean, Japan, Australia and elsewhere)







Key Aspects of the NEEA/ASSETS approach

The NEEA/ASSETS approach may be divided into three parts:

- ✓ **Division of estuaries into homogeneous areas**
  - Tidal freshwater (<0.5 psu)
  - Mixing zone (0.5-25 psu)
  - Seawater zone (>25 psu)
- ✓ **Evaluation of data completeness and reliability**
  - Spatial and temporal quality of datasets (completeness)
  - Confidence in results (sampling and analytical reliability)
- ✓ **Application of indices**

Overall Human Influence (OHI) index ------------------ Pressure

Overall Eutrophic Condition (OEC) index ------------------ State

Determination of Future Outlook (DFO) index ------------------ Response

S.B. Bricker, J.G. Ferreira, T. Simas, 2003. An integrated methodology for assessment of estuarine trophic status. Ecological Modelling, 169: 39-60.

Overall Human Influence (OHI) - Pressure

Susceptibility + Nutrient Inputs = Overall Human Influence

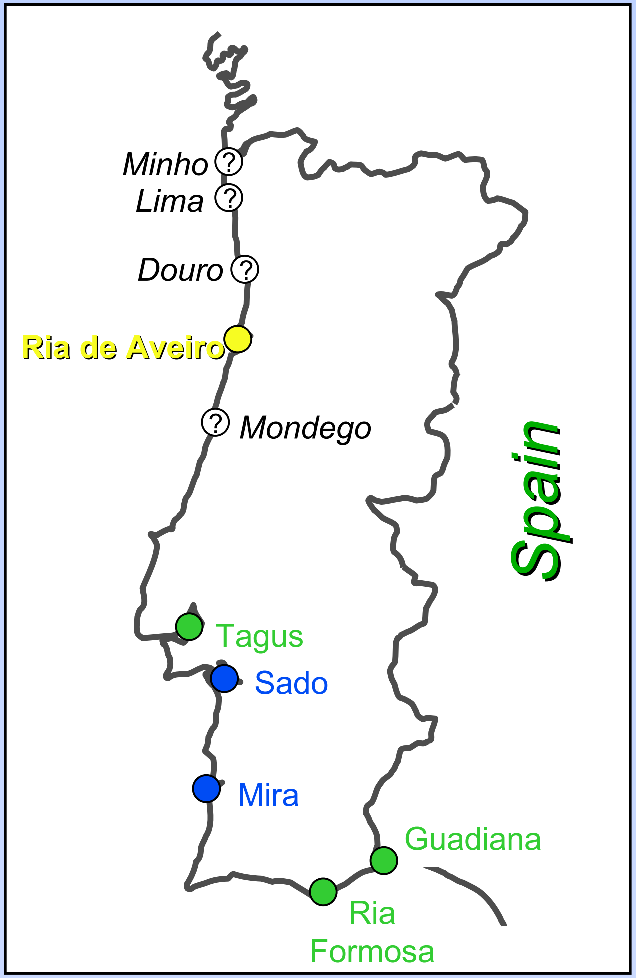
dilution & flushing — land based or oceanic

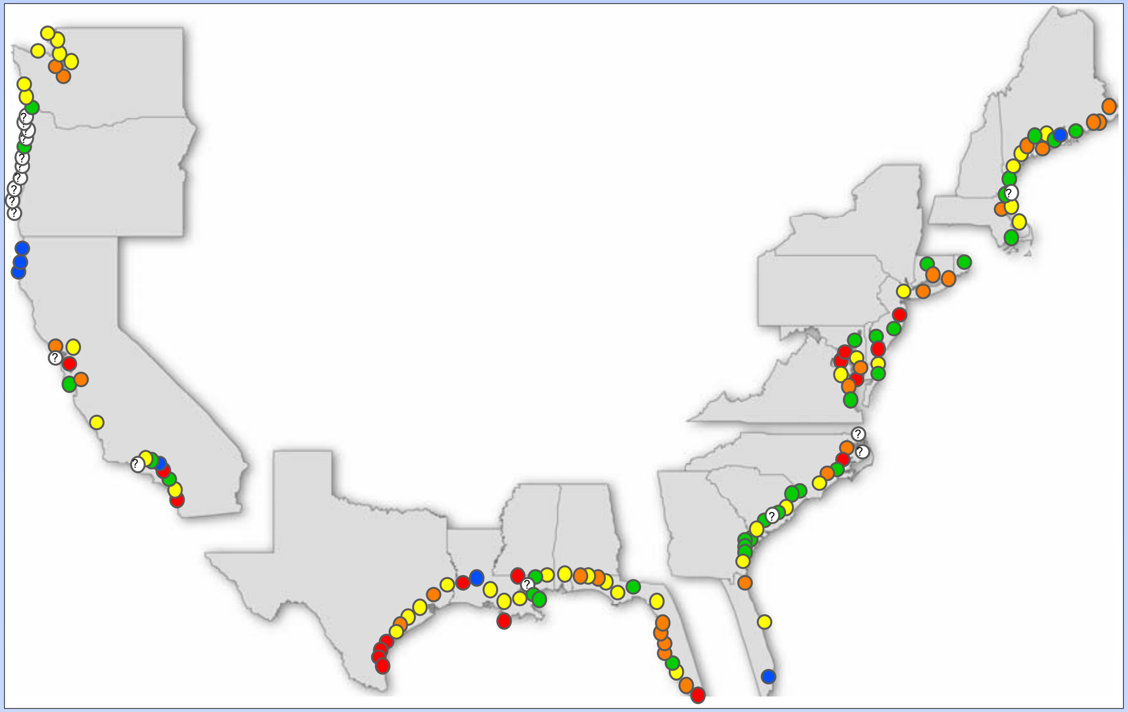
Region	Susceptibility H	M	L	Nutrient Inputs* (as %) >50% NPS	1^{o} from Ag
North Atlantic	**0**	**6**	**12**	**78**	**0**
Mid Atlantic	**15**	**7**	**0**	**91**	**60**
South Atlantic	**8**	**9**	**4**	**100**	**81**
Gulf of Mexico	**12**	**23**	**2**	**100**	**85**
Pacific	**14**	**18**	**7**	**89**	**50**
US Total	**49**	**63**	**25**	**92**	**56**
Portugal	**0**	**5**	**5**	**89**	**67**

(Barnegat Bay – High susceptibility: low dilution and moderate flushing potentials,
Nutrient inputs: ~100% nonpoint, 40% atmosp., 24% ag, 35% urban)

**as percentage of 130 US, 9 PT systems ; US:SPARROW model estimates, PT: Ferreira et al 2003*

Overall Eutrophic Conditions (OEC) - State



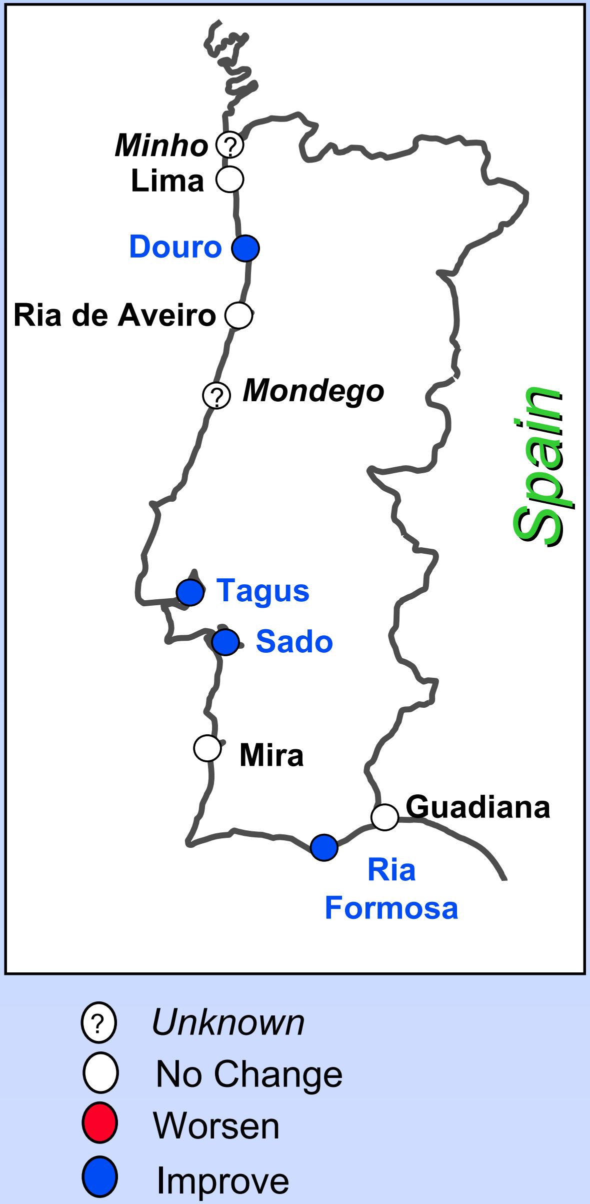


Unknown
High
Moderate High
Moderate
Moderate Low
Low

OEC	US	PT
High	12	0
Mod. High	10	0
Moderate	28	10
Mod. Low	23	30
Low	5	20
Unknown	12	40

as percent of 139 US and 10 PT systems

Determination of Future Outlook (DFO) - Response



DFO	US	PT
Improve	6	40
No Change	32	40
Worsen	62	0
Unknown	0	20

as percent of 139 US and 10 PT systems

Overall Human Influence (OHI) - Pressure

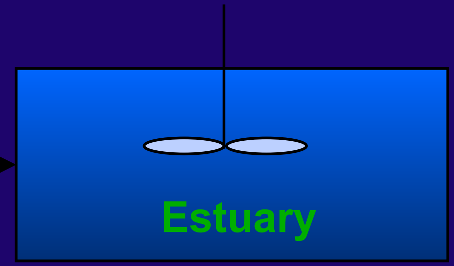
- Calculate m_h, the expected nutrient concentration due to land based sources (i.e. no ocean sources);
- Calculate m_b, the expected background nutrient concentration due to the ocean (i.e. no land-based sources);
- Calculate OHI as the ratio of $m_h/(m_h+m_b)$;

Class	Thresholds
Low	0 to <0.2
Moderate low	0.2 to <0.4
Moderate	0.4 to < 0.6
Moderate high	0.6 to < 0.8
High	>0.8

Equations are based on a simple Vollenweider approach, modified to account for dispersive exchange:

Anthropogenic inputs

$$m_h = \frac{m_{in}\left(s_o - s_e\right)}{s_o}$$



Ocean inputs

$$m_b = \frac{m_{sea} s_e}{s_o}$$

Bricker et al. 2003 and Ferreira, Bricker and Simas. Application and sensitivity testing of an eutrophication assessment method on US and EU coastal systems. Submitted L&O.

Overall Eutrophic Condition (OEC) - State

NEEA Methodology

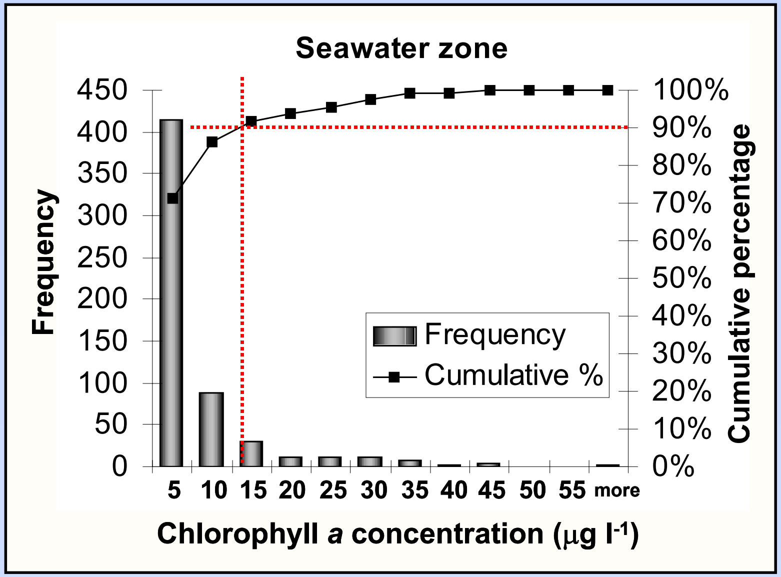
1) Determine level of expression for Chl a, macroalgae, epiphytes, D.O., SAV loss and HABs for each zone (combines concentration/observance, spatial coverage, frequency of occurrence) by logic tree

2) Determine and overall estuary expression for primary (average symptom values) and secondary (highest symptom value) symptoms

3) Combine overall primary and secondary for overall estuary by matrix

$$S_l = \sum_{1}^{n} \left(\frac{A_z}{A_e} E_l \right)$$

Where:
A_z: Surface area of zone
A_e: Total estuarine surface area
E_l: Expression value at each zone
n: Number of estuarine zones



ASSETS Adaptations to OEC

Expert knowledge replaced by:

- Data: Level of expression is based on data, cumulative frequency (Chl *a* = 90th percentile; DO = 10th percentile)
- Spatial area : determined by GIS or Grid

Decision/Logic Example for Chl *a*

IF	AND	AND	THEN	
Concentration	Spatial Coverage	Frequency	Expression	Value
Hypereutrophic *or* High	High	Periodic	High	1
	Moderate	Periodic	High	1
	Low	Periodic	Moderate	0.5
	Very Low	Periodic	Moderate	0.5
	High	Episodic	High	1
	Moderate	Episodic	Moderate	0.5
	Low/Very Low	Episodic	Low	0.25
	Any Spatial Coverage	Unknown	Flag A	0.5
	Unknown	Any Frequency	Flag A	0.5

Flags are used to identify impacts for which not enough data was available for the components. In these cases, assumptions were made based on conservative estimates that unknown spatial coverage is at least 10 percent of the zone, unknown duration is at least days, and unknown frequency is at least episodic.

Matrix for Determining Overall Eutrophic Condition

Overall level of expression of eutrophic conditions

	Low secondary symptoms (0–0.3)	Moderate secondary symptoms (0.3–0.6)	High secondary symptoms (0.6–1)
High primary symptoms (0.6–1)	MODERATE Primary symptoms high but problems with more serious secondary symptoms still not being expressed	MODERATE HIGH Primary symptoms high and substantial secondary symptoms becoming more expressed, indicating potentially serious problems	**HIGH** **High primary and secondary symptom levels indicate serious eutrophication problems**
Moderate primary symptoms (0.3–0.6)	MODERATE LOW Primary symptoms beginning to indicate possible problems but still very few secondary symptoms expressed	MODERATE Level of expression of eutrophic conditions is substantial	**HIGH** **Substantial levels of eutrophicconditions occuringwith secondary symptoms indicating serious problems**
Low primary symptoms (0–0.3)	LOW Level of expression of eutrophic conditions is minimal	MODERATE LOW Moderate secondary symptoms indicate substantial eutrophic conditions, but low primary indicates other factors may be involved	MODERATE HIGH High secondary symptoms indicate serious problems, but low primary indicates other factors may also be involved in causing conditions

Determination of Future Outlook (DFO) - Response

Future outlook is based on susceptibility and projected changes in nutrient pressures:

Future Outlook For Eutrophic Conditions

Susceptibility	Decrease	No Change	Increase
Low	Improve High	No Change	Worsen Low
Moderate	Improve Low	No Change	Worsen High
High	Improve Low	No Change	Worsen High

Future Nutrient Pressures

Susceptibility is the capacity of a system to dilute or flush nutrients

Nutrient pressure changes are based on expected population changes, future treatment and remediation plans and changes in watershed use (particularly agricultural)

Additional Adaptation: Synthesis of OHI - OEC - DFO

Grade	5	4	3	2	1
OHI	Low	Moderate low	Moderate	Moderate high	High
OEC	Low	Moderate low	Moderate	Moderate high	High
DFO	Improve high	Improve low	No change	Worsen low	Worsen high

Metric	Combination matrix	Class
P S R	$\begin{vmatrix} 5&5&5&4&4&4 \\ 5&5&5&5&5&5 \\ 5&4&3&5&4&3 \end{vmatrix}$	High (5%)
P S R	$\begin{vmatrix} 5&5&5&5&5&5&5&4&4&4&4&4&3&3&3&3&3&3 \\ 5&5&4&4&4&4&4&5&5&4&4&4&5&5&5&4&4&4 \\ 2&1&5&4&3&2&1&2&1&5&4&3&5&4&3&5&4&3 \end{vmatrix}$	Good (19%)
P S R	$\begin{vmatrix} 5&5&5&5&5&4&4&4&4&4&4&4&3&3&3&3&3&3&3&2&2&2&2&2&2&2&2&2&1&1 \\ 3&3&3&3&3&4&4&3&3&3&3&3&5&5&4&4&3&3&3&4&4&4&4&4&3&3&3&2&3&3 \\ 2&1&5&4&3&2&1&5&4&3&2&1&2&1&2&1&5&4&3&5&4&3&2&1&5&4&3&5&5&4 \end{vmatrix}$	Moderate(32%)
P S R	$\begin{vmatrix} 4&4&4&4&4&3&3&3&3&3&3&3&2&2&2&2&2&2&1&1&1&1&1 \\ 2&2&2&2&2&3&3&2&2&2&2&2&3&3&2&2&2&2&3&3&3&2&2 \\ 5&4&3&2&1&2&1&5&4&3&2&1&2&1&4&3&2&1&3&2&1&5&4 \end{vmatrix}$	Poor (24%)
P S R	$\begin{vmatrix} 3&3&3&3&3&2&2&2&2&2&1&1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1&1&1&1&2&2&2&1&1&1&1&1 \\ 5&4&3&2&1&5&4&3&2&1&3&2&1&5&4&3&2&1 \end{vmatrix}$	Bad (19%)

Grades for OHI, OEC and DFO are combined into a grade of High, Good, Moderate, Poor and Bad with color coding to match the EU WFD convention.

Combinations were distributed heuristically and impossible or improbable combinations were excluded.

Barnegat Bay – NEEA/ASSETS Application

ASSETS: BAD

Indices	Methods	Parameters	Rating	Level of expression	Index
Overall Human Influence (OHI) ASSETS: 1	Susceptibility	Dilution potential	Low	High susceptibility	HIGH
		Flushing potential	Moderate		
	Nutrient inputs			High nutrient input	
Overall Eutrophic Condition (OEC) ASSETS: 1	Primary	Chlorophyll *a*	High	High	HIGH
		Epiphytes	No Data		
		Macroalgae	Moderate		
	Secondary	Dissolved Oxygen	No Problem	High	
		Submerged Aquatic Vegetation	Moderate		
		Nuisance and Toxic Blooms	High		
Determination of Future Outlook (DFO) ASSETS: 4	Future nutrient pressures	Future nutrient pressures decrease			IMPROVE LOW

Estuary Characteristics:

Population (X 10^3)	588- 800
Nutrient loading (tN y^{-1})	720
Mean depth (m)	1.4
Mean tidal range (m)	0.9
Water residence time (d)	27-71

Main impacts:

Chlorophyll a
HABs
Macroalgae

Ria Formosa – NEEA/ASSETS Application

ASSETS: GOOD

Indices	Methods	Parameters expression	Rating	Level of	Index
Overall Human Influence (OHI) ASSETS: 3	Susceptibility	Dilution potential	High	Moderate susceptibility	MODERATE
		Flushing potential	Low		
	Nutrient inputs	Moderate nutrient input			
Overall Eutrophic Condition (OEC) ASSETS: 4	Primary	Chlorophyll *a*	Low	Moderate	MODERATE LOW
		Epiphytes	Moderate		
		Macroalgae	High		
	Secondary	Dissolved Oxygen	No Problem	Low	
		Submerged Aquatic Vegetation	Low		
		Nuisance and Toxic Blooms	No Problem		
Determination of Future Outlook (DFO) ASSETS: 4	Future nutrient pressures	Future nutrient pressures decrease			IMPROVE LOW

Estuary Characteristics:

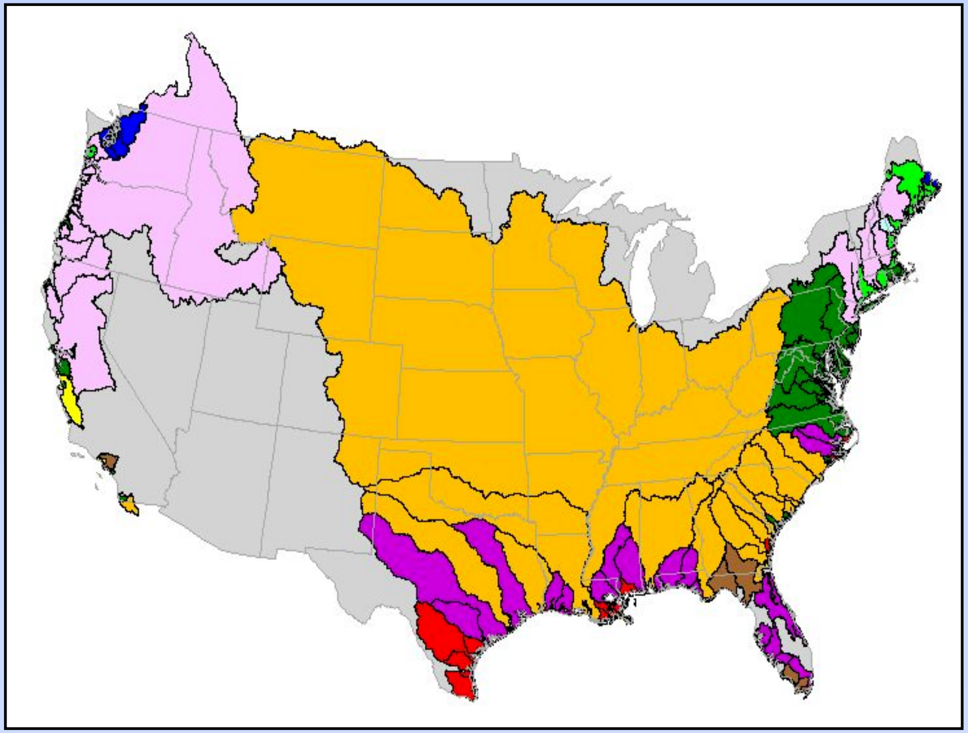
Population (X 10^3)	124-211
Nutrient loading (tN y^{-1})	1028
Mean depth (m)	1.9
Mean tidal range (m)	2
Water residence time (d)	0.5-2

Main impacts:

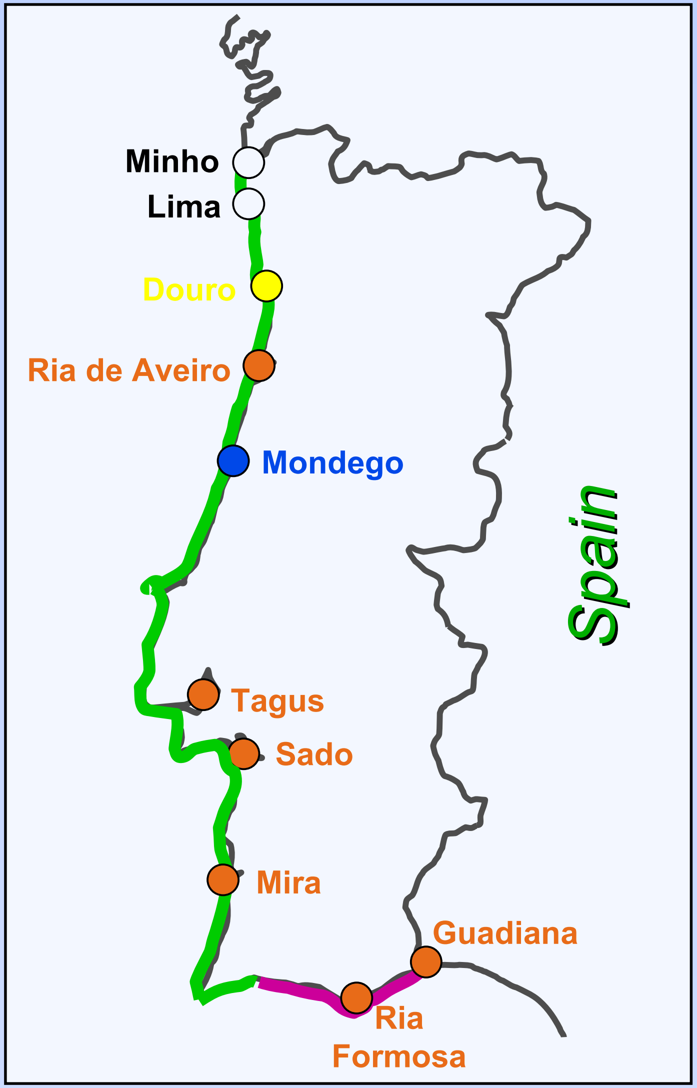
Macroalgae
Intertidal O_2
Bivalve mortality

Typology: DISCO Cluster Results

Classification based on physical and hydrologic characteristics – nutrients will be processed differently in systems that flush well or flush poorly and management strategies will be different

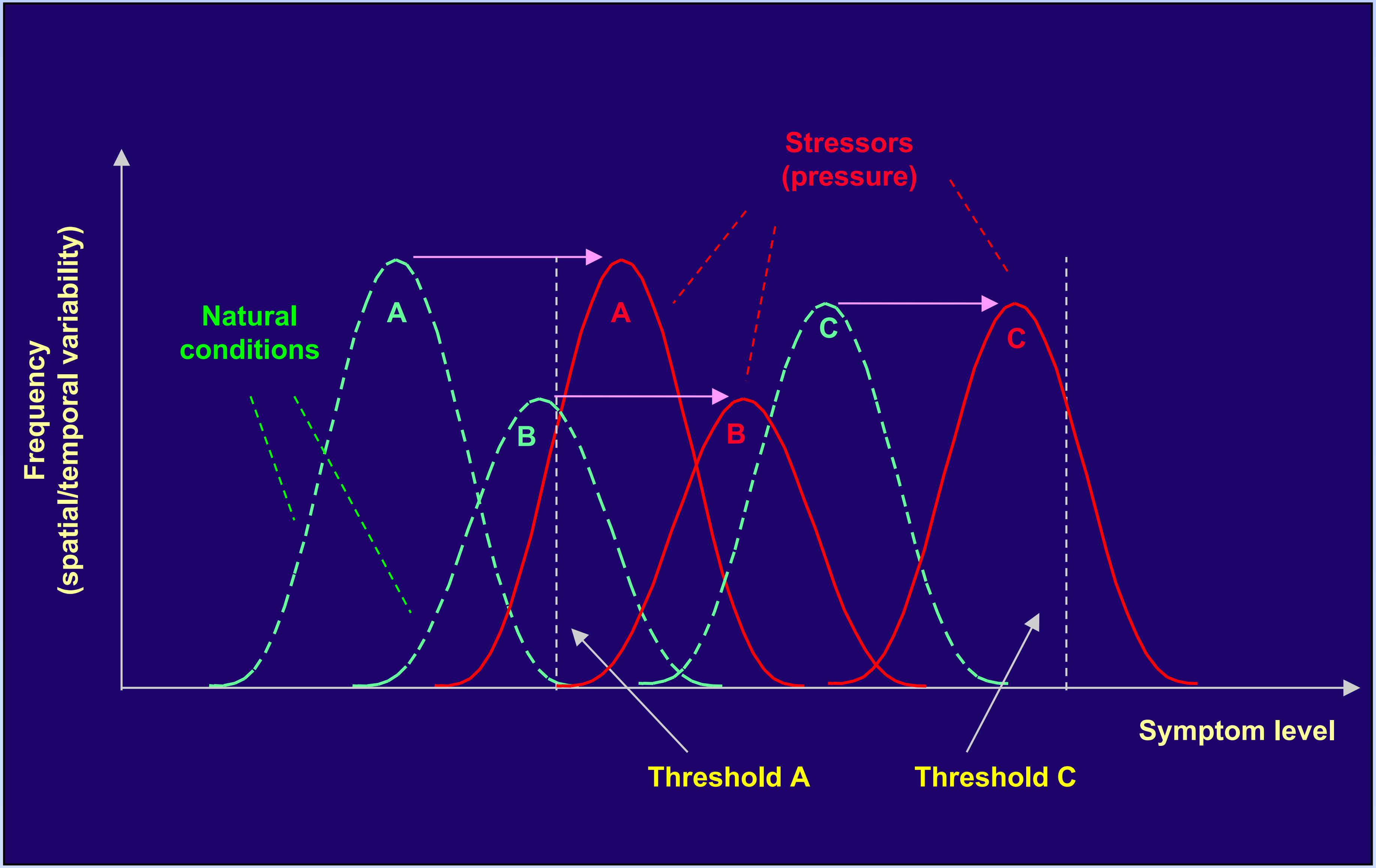


A top-down classification resulted in 14 types.
DISCO gives 10 types (120 of 138 within 6 types).
Characteristics: Mean depth; % open mouth; Tide height; log (freshwater flow/area); Mean air temperature.

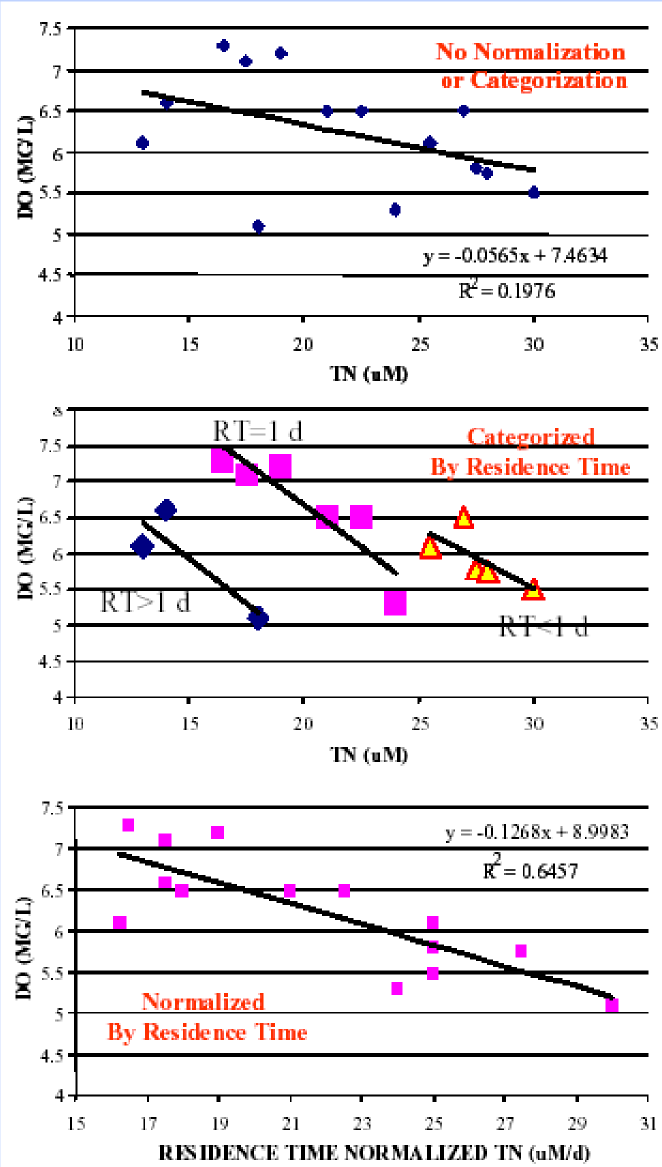


A top-down classification resulted in 7 types.
DISCO gives 6 types but semi-enclosed lagoons were not included

Typology: Ecosystem Reality



Typology: Reference Conditions



From: Latimer and Kelly. 2003. Proposed classification for predicting sensitivity of coastal receiving waters to effects of nutrients. US EPA.

14 small tidally flushed embayments in Maine are categorized and normalized for residence time.

Thresholds for nutrient loading (TN) and reference conditions for D.O. are different for different systems depending upon residence time.

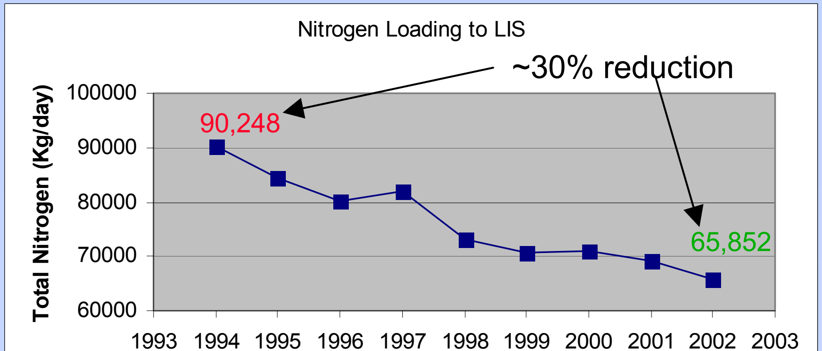
Similarly, Chl *a* ranges for classification of status vary by type

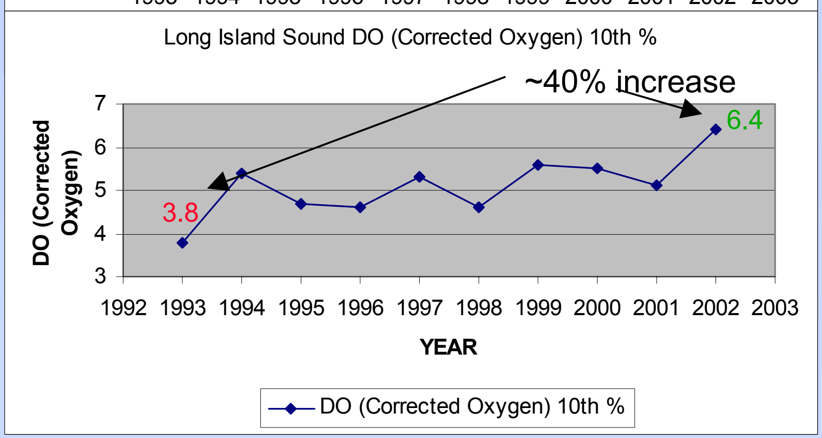
Chlorophyll *a* (ug/l)	NEEA	Sensitive Systems
Hypereutrophic	>60	>5
High	20 - 60	2 - 5
Medium	5 - 20	1 - 2
Low	0 - 5	0 - 1

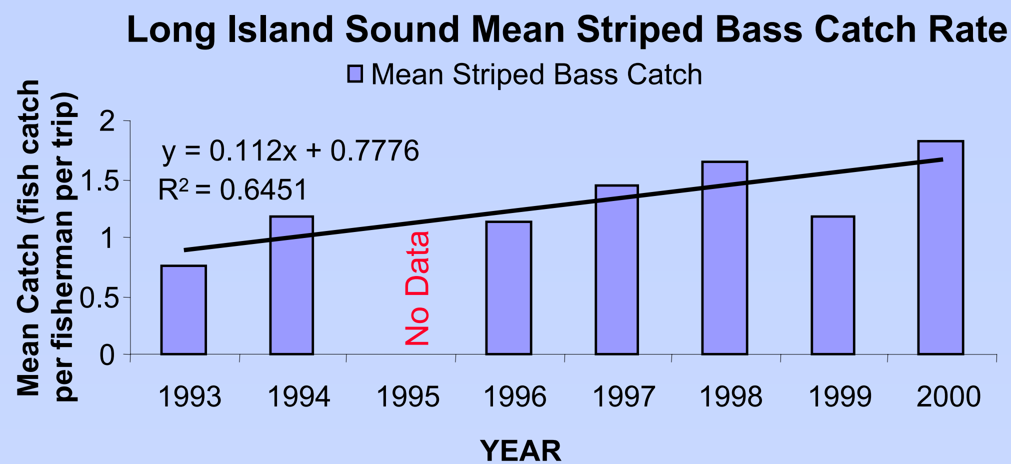
NEEA/ASSETS applied Chl *a* ranges universally, however, for sensitive systems, e.g. Florida Bay, 5 ug/l indicates severe problems.

Socioeconomic Pilot: Fish Catch & Water Quality

Premise: Fish catch will decrease as water quality declines, economic losses result
Study: Compares fish catch among 13 sites (9 in Gulf of Maine, Narragansett, Long Island Sound, Patuxent and Potomac Rivers) with different water quality (D.O.)







- ~30% Reduction in Nitrogen Loading
- ~40% Increase of DO 10th Percentile
- Significant Increase in Striped Bass Catch Rate

From A. Mason ASLO 2004 presentation: *Improving indicators of water quality degradation impacts for management of estuaries and coastal*

This indicator will provide insight to the consequences of eutrophication and provide justification for management action

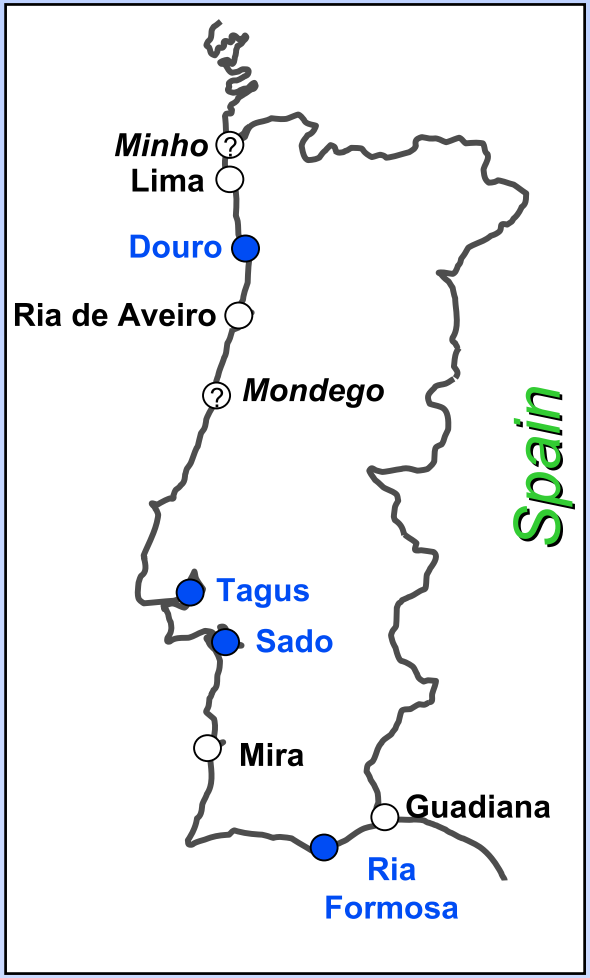
Ria Formosa –ASSETS validation & model scenarios

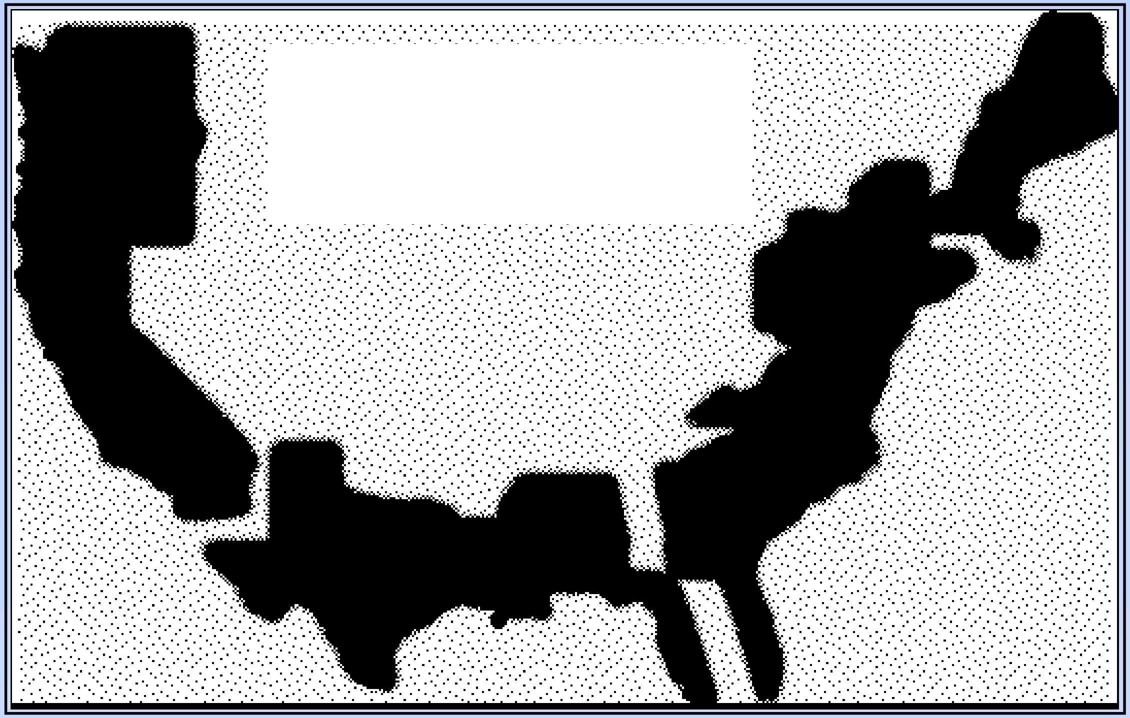
Index	Methods	Parameters expression	Value	Level of	Index
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25		MODERATE LOW
	Field data	Epiphytes	0.50	0.57	
		Macroalgae	0.96	Moderate	
ASSETS OEC: 4	SSM	Dissolved Oxygen	0		
		Submerged Aquatic Vegetation	0.25	0.25 Low	
		Nuisance and Toxic Blooms	0		
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25		MODERATE LOW
	Research model	*Epiphytes*	*0.50*	0.58	
		Macroalgae	1.00	Moderate	
ASSETS OEC: 4	SSM	Dissolved Oxygen	0		
		Submerged Aquatic Vegetation	0.25	0.25 Low	
		Nuisance and Toxic Blooms	0		
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25		MODERATE LOW
	Model green scenario	*Epiphytes*	*0.50*	0.42	
		Macroalgae	0.50	Moderate	
ASSETS OEC: 4(5)	SSM	Dissolved Oxygen	0		
		Submerged Aquatic Vegetation	0.25	0.25 Low	
		Nuisance and Toxic Blooms	0		

28% lower

Nobre, Ferreira, Newton, Simas, Icely, Neves. Managing eutrophication: Integration of field data, ecosystem-scale simulations and screening models. Submitted L&O. (www.eutro.org)

Determination of Future Outlook (DFO) - Pressure



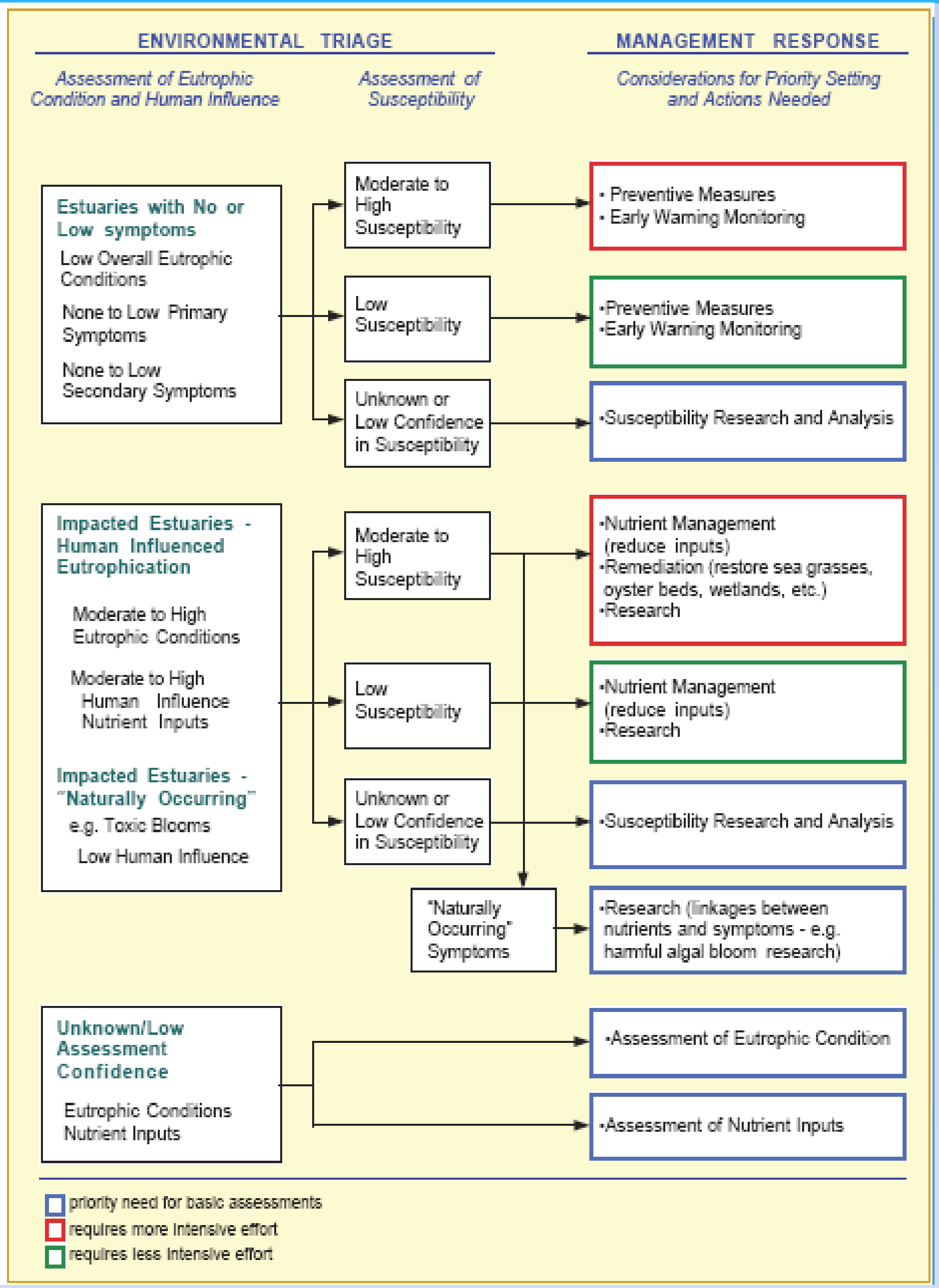


DFO	US	PT
Improve	6	40
No Change	32	40
Worsen	62	0
Unknown	0	20

as percent of 139 US and 10 PT systems

- *Unknown*
- No Change
- Worsen
- Improve

Response: Management, Monitoring & Research



Concluding Remarks

- **NEEA/ ASSETS is a transferable methodology to evaluate eutrophication status, influencing factors, and future outlook for guidance and prioritization of management resources**

- **Improvements have been made to the original method, however, additional modifications are necessary and are in progress**

- **Application of the method shows Barnegat Bay to be highly eutrophic (Bad)**

- **Additional improvements will improve accuracy:**
  - **-- development of typology,**
  - **-- re-evaluation of thresholds for indicator variables and inputs for different types of estuaries,**
  - **-- re-evaluation of variables, use core for all systems, additional variables as appropriate by type,**
  - **-- addition of socio-economic indicator,**
  - **-- development of models/tools to predict the impact of different management scenarios**

Concluding Remarks

Assessment method improvements are the focus of NOAA's National Estuarine Eutrophication Assessment Update Program which includes national and international partners

http://www.eutro.org